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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

# THE NOW FRONTIER

## LINKING EARTH AND PLANETS

(NASA-CR-142827) INNERMOST PLANETS OF THE  
SOLAR SYSTEM (Jet Propulsion Lab.) 4 p HC  
\$3.25 CSCL 03A

N75-24627

Unclas

G3/91 21871

## Innermost Planets of the Solar System



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ISSUE NUMBER ONE

PUBLIC EDUCATIONAL SERVICES OFFICE

## THE INNER PLANETS

The dull-white star shone steadily across the Aegean Sea in the warm glow of dawn. The Ancient Greeks called this star Apollo. And they thought it different from another dull-white star that often lingered for a few weeks in the sunset glow across the Ionian Sea. This star they called Mercury, the messenger of the gods. But by the time of Plato, the Greeks had discovered that the two stars are one, and are not stars, but a wandering planet always moving close to the Sun like a moth around a candle flame.

Mercury is the innermost planet of the solar system. Venus orbits the Sun between the orbits of Earth and Mercury. Both planets are now targets for a Mariner 10 spacecraft launched November 1973 and scheduled to fly past Venus in February 1974, and Mercury in March 1974. Venus has been reached several times by spacecraft from the U.S. and the U.S.S.R., but Mercury has never before been reached.

Mercury averages 36 million miles from the Sun, about 40 percent of Earth's distance, while Venus, at 67 million miles, is about 75 percent of Earth's distance from the Sun.

Since the planet Mercury is so close to the Sun and moves rapidly in its orbit ( $1\frac{1}{2}$  to 2 times faster than Earth) it flits from side to side of the Sun to be seen only just before sunrise and just after sunset. Its rapid motion and brief appearances and disappearances probably caused the ancients to associate it with the winged-foot messenger of mythology.

By contrast, Venus is closer to Earth, moves further away from the Sun in the evening and morning skies, appears placid and brilliant and is perhaps the most beautiful object in the skies—"Mistress of the Heavens" said the Babylonians. This planet was accord-

*Cover: Mercury and Venus — the innermost planets of the solar system — are shown here in their orbits around the Sun: first, Mercury (seen here as a crescent), and then Venus; the Earth is next, with our Moon close to it. Planets farther from the Sun are Mars, Jupiter (shown with some of its satellites), and Saturn, with its rings. Uranus, Neptune, and Pluto are the most distant planets.*

ingly associated with the Roman goddess of beauty, Venus.

Planets of the solar system consist of two distinct types: small, dense, inner planets with solid surfaces—Mercury, Venus, Earth and its Moon, and Mars—and large, predominantly gaseous outer planets—Jupiter, Saturn, Uranus, and Neptune. Pluto, the outermost known planet, cannot be observed well enough to be accurately classified, though it is believed to be similar to the inner planets.

Also, between the orbits of Mars and Jupiter is a zone of minor planets called asteroids, the largest of which, Ceres, is only about 500 miles in diameter, while most are much smaller.

In distance outwards from the Sun, the asteroids divide the inner from the outer planets, Jupiter being the first of the outer planets, Mars the most distant of the inner planets.

## ANALOGY WITH EARTH AND MOON

Venus is approximately the same size and mass as Earth, Mercury somewhat larger than Earth's Moon. While Earth and Venus both have atmospheres, the Moon, and, apparently, Mercury, are airless bodies. Venus and Mercury might have been a twin system like Earth and Moon, except that the closeness of Venus to the Sun probably prevented Mercury from being a satellite of Venus and prevented Venus from possessing a terrestrial-type atmosphere and oceans.

From the point of view of planetary dynamics, Mercury is perhaps the most important object in the solar system. Being the closest planet to the Sun, it is the most sensitive detector of departures from the laws proposed to account for planetary orbital motions. An unusual period of spin and an unusually high density make Mercury of great interest to astronomers.

A space probe flying by Mercury can provide important information about both the dynamics of Mercury and its interior. The radius, mass, and orbit can be refined.

Venus is the planet most similar to the Earth in size, density, and distance from the Sun. However, it differs significantly in having a

much more massive atmosphere composed mainly of carbon dioxide, a much higher surface temperature, about  $700^{\circ}\text{K}$ , a much slower backwards rotation period of 243.1 Earth days, and no moon or oceans.

Spacecraft traveling to Venus in the past have not detected a significant magnetic field (the field being less than  $1/5000$  of the Earth's).

The closeness of the mean density of Venus to that of the Earth might imply that the chemical composition of the two planets is almost the same. A question often asked is whether Venus is at a stage earlier or later in evolution than the Earth, or follows an entirely different evolutionary path from Earth.

Radar inspection of Venus from Earth reveals a surface that is generally smoother than the Moon and gently undulating. There are, however, several regions that appear to be much rougher than their surroundings, and some large shallow craters.

## SOLAR ORBITS AND APPEARANCE OF INNER PLANETS IN THE SKY (APPARITIONS)

It is instructive to look at Mercury and Venus from the standpoint of the early astronomers. Earthbound, they watched the motions of the planets against the background of stars and deduced that the planets, including the Earth, move around the Sun in almost circular orbits. Because Mercury and Venus orbit the Sun inside the Earth's orbit, they are termed inferior planets.

As seen from the Earth, inferior planets appear to move close to the ecliptic (the apparent yearly path of the Sun relative to the stars, which is the plane of the Earth's orbit projected against the stars), and to move backwards and forwards, oscillating to either side of the Sun and never far from it in the sky (Figure 1). The maximum distance to east or west of the Sun is termed elongation. At eastern elongation, Mercury and Venus are seen in the evening sky as evening stars because they appear to follow the Sun in its daily motion across Earth's sky due to the rotation of the Earth. At western elongation, they are ahead of the Sun and are seen as morning stars before sunrise.

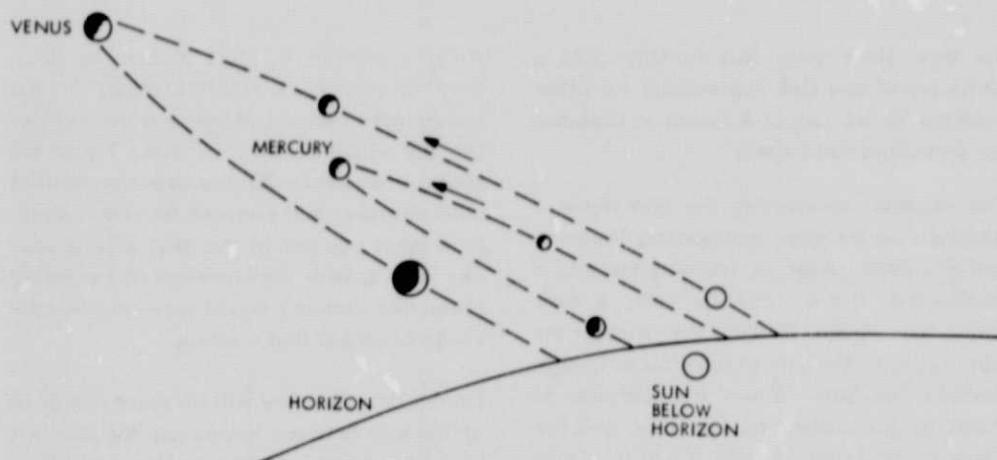


Figure 1. The appearance of Mercury and Venus as evening stars as they travel around the Sun, inside the orbit of Earth.

Because the orbits of these inferior planets are completely contained within the Earth's orbit, both Mercury and Venus pass between Earth and Sun. This is termed inferior conjunction. When the planets are on the far side of the Sun from Earth, they pass through superior conjunction. And because the orbits of the Earth and the two planets are not exactly in the same plane, that is, they are tilted slightly with respect to each other like crossed hoops, Mercury and Venus normally pass through conjunction above or below the Sun. Infrequently the orbits line up so that the planets pass across the face of the Sun in a transit or behind the Sun in occultation. Occultations are not observable because of the brilliance of the Sun, but transits are. (It was Captain Cook's voyage to observe a transit of Venus where it was visible in the South Pacific that lead to his discovering Tahiti.)

Transits of Venus occur very rarely: the most recent occurred in 1882, the next are not due until the beginning of the next century—June 7, 2004, and June 5, 2012 (they occur in close pairs). Transits of Mercury occur much more frequently. One was visible from the East Coast of the United States on November 11, 1973. The next transit will take place on November 12, 1986.

Mercury revolves around the Sun in a period of 88 days, Venus in a period of 225 days. But their visibility in Earth's skies must also take account of Earth's movement around the Sun. So Venus repeats its apparitions (elongations and conjunctions) approxi-

mately every 584 days. Mercury repeats approximately every 116 days. But since Mercury's orbit varies much more from a true circle than does that of Venus, the repetition of Mercury's positions relative to the Sun in Earth's skies varies too.

The distance of Mercury from the Sun in the sky at elongation also varies, from only 18 degrees to as much as 27 degrees, and thus affects its visibility. Mercury is a relatively dull object. Like the Moon, it does not reflect much of the sunlight falling on it, so it does not appear very bright in the sky. Moreover, Mercury can rise before the Sun or set after the Sun by only 2¼ hours, so it is rarely seen in a dark sky, but usually only in the twilight glow, low down near the horizon, competing with the sunset. And the planet cannot be seen for much longer than two weeks close to the time of its elongation. There is an average interval of 44 days between Mercury's appearance as an evening and a morning star.

By contrast, Venus can move as much as 47 degrees from the Sun and can be seen in the late evening or early morning skies as the brightest object after the Moon. Venus reflects a large proportion of the Sun's light falling upon it and it appears very bright in the skies of Earth. Venus is brightest about one month before and after inferior conjunction, when a telescope shows it as a fat crescent shape. It can then become so bright as to cast distinct shadows. The planet can be observed for many months and has even been observed through binoculars as it passes

above or below the Sun at closest approach. It is also clearly visible in daylight if an observer knows where to look; for example, when the planet appears close to the Moon in the sky. Venus passes from greatest elongation as an evening star to greatest western elongation as a morning star in about 140 days, and from a morning star back to an evening star in about 430 days.

## SIGHTINGS AND MOTIONS IN THE SKY

During December 1973, Venus was a brilliant evening star close to the planet Jupiter. Venus passed between Earth and Sun on January 24, appearing above the Sun as seen from Earth's northern hemisphere. Then Venus becomes a brightening morning star through February and March, gradually rising earlier and earlier before sunrise (Figure 2).

Mercury is an evening star observable from the beginning of February through about the third week of that month, then passes above the Sun early in March and becomes a morning star with good elongation from the Sun towards the end of March. Unfortunately, Mercury as a morning star in the spring is not well suited to observation since it is very close to the horizon south of the point of sunrise (Figure 3). It will be in the constellation Aquarius, where there are not many bright stars to help identify the planet.

Venus, too, will be in Aquarius at this time but will be unmistakable because of its brightness, even though it is also close to the horizon.

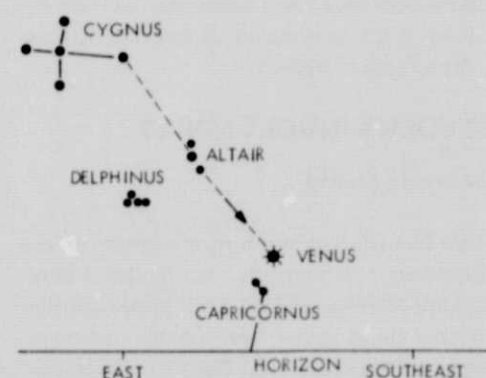
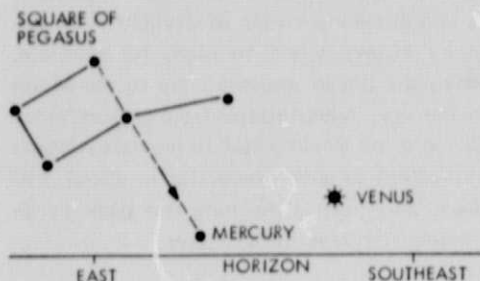


Figure 2. Venus at the day of Mariner 10 flyby (February 5, about 6:30 a.m., Pacific Standard Time).





**Figure 3. Mercury at the day of Mariner 10 flyby (March 29, about 6:00 a.m., Pacific Standard Time).**

The comet Kohoutek, visible in late December and early January close to Venus and Jupiter in the evening sky, will still be a faint object in the evening sky when Venus and Mercury have become morning stars during February.

## PHASES OF THE INNER PLANETS

As the inferior planets move around the Sun they display phases, as seen from Earth, comparable to those of the Moon. When Mercury and Venus are on the far side of the Sun they appear fully illuminated like a full Moon, but because of their great distances they are then unfavorably placed for observation and show only very small discs. At eastern and western elongations, Mercury and Venus appear half illuminated, like half-moons. Then as they swing between Earth and Sun, the planets display a narrowing crescent phase to Earth until, if they cross the disc of the Sun, they appear as black spots upon it. Most times they pass either slightly above or below the Sun as seen from Earth and thus, in a telescope, can be observed as a fine crescent all the way through inferior conjunction.

## STUDENT INVOLVEMENT

### Classroom Project

Have one student stand in the center of the classroom (which is preferably semi-darkened) to represent the Sun. Have another student stand at the front of the class to represent the observer on Earth. Position two other students to represent Mercury and Venus, the first almost half way between Sun and Earth, the second three quarters of

the way. Have these two students hold a white styrofoam ball, big enough for other students to see (about 4 inches in diameter for a medium-sized class).

The student representing the Sun shines a flashlight on the globe representing Mercury, and the Earth observer, standing close to a blackboard, draws what he sees, a dark globe. The student Mercury then moves part way round to the side of the class as though orbiting the Sun. Again the flashlight is shone on the globe from the Sun, and the Earth student now draws the half-lit planet he sees.

The Venus student demonstrates likewise, then the class is asked to draw the visible illuminated shapes of Venus and Mercury as these planets move around the Sun as seen from Earth, at closest approach to Earth, at greatest elongations, and when most distant from Earth.

### Student Project One

Early in January, look at the evening sky when it starts to become dark after sunset. The Sun sets in the southwest. Look left from the sunset point, and close to the horizon there will be a fairly bright star, which is the planet Venus. If you have access to a small telescope or very good field glasses you will be able to see that it is shaped like a tiny, very fine crescent Moon. If Comet Kohoutek is still a bright object, Venus will be between the head of the comet and the point on the horizon where the Sun set. In the following days, observe how Venus moves deeper and deeper into the sunset glow until it finally disappears.

About the first week in February, get up before sunrise and look for Venus in the morning skies before the Sun comes up and while the sky is still fairly dark. Try to see Venus on February 5, since this will be the day when the Mariner spacecraft flies past the planet.

Continue to observe Venus in the following weeks and watch how it moves further from the sunset glare and becomes brighter day by day. If you have access to a telescope observe, too, that it is now a crescent facing opposite to the way it faced when it was an evening star.

Around mid-March, start looking for Mercury, a very faint star-like object in the morning sky between Venus and the point of the sky where the Sun will rise. Try to see Mercury on March 29, the date Mariner flies past Mercury, and you will be able to compare what you see in the sky, a faint star-like object, with the close-ups of a possibly Moon-like cratered world seen on the television newscasts that evening.

On this date, Mercury will be about one-third of the way between Venus and the Sun but below the direct line between Venus and Sun. Of course you will not be able to see either when the Sun is in the sky unless you observe with a precisely pointed astronomical telescope, so you will have to estimate where the Sun is below the horizon.

### Student Project Two

This can also be a classroom project on the blackboard. Refer to an astronomical textbook and draw a plan map of the solar system showing the orbits of Mercury, Venus, and Earth. Try to draw them to scale, and note that Mercury's orbit seems offset to one side of the Sun. Then try to work out where the Earth and the two planets must be to be seen in the sky as they are. Remember, as seen from above (north), Earth rotates on its axis and all the planets revolve around the Sun in a counterclockwise direction. Remember, too, that Venus moves between Earth and Sun on January 24, and Mercury between Earth and Sun around February 25. Plot points on the orbits every ten days working backwards and forwards from the times of conjunction. Save your solar system plan map for a later exercise.

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